Caving Cu-Au Porphyry

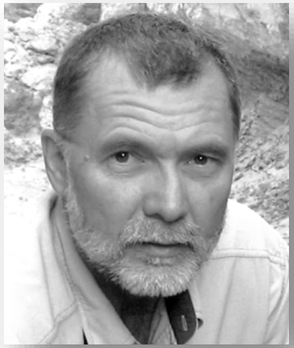
Prepared by Jarek Jakubec
March 7, 2016

PROSPECTORS & DEVELOPERS ASSOCIATION OF CANADA

Cave Mining Cu-Au Porphyry

There are over 45 cave mining projects in various stages of studies and development around the world. Cave mining methods will be the underground method of choice in the future. It is only relatively recent that this mass mining method, despite 70 years of use, has begun proving its potential.

That interest is being fueled by the depletion of near surface ore bodies suitable for open pit operations. Many mining companies are turning to cave mining when they need to transition their operations from open pit to underground or if they need to exploit large low-grade resources at depth which would not support a more expensive mining method. Cave mining methods are becoming more popular due to relatively higher metal prices, projected supply and demand forecasts, and a lower discovery rate of significant new surface deposits. Cave mining is the primary underground mining method for extracting large Cu-Au porphyry deposits and this talk will highlight some of the recent development and challenges.



Jarek Jakubec, SRK Corporate Consultant, has over 30 years of operating and consulting experience in Mining, Geology and Rock Mechanics and his focus is on mass mining. Jarek has been involved in various capacities in most of the cave mines and cave mining projects around the world. He participated on several research programs, published numerous papers and most currently in collaboration with Infomine and UBC introduced web based Cave Mining Forum.

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Agenda

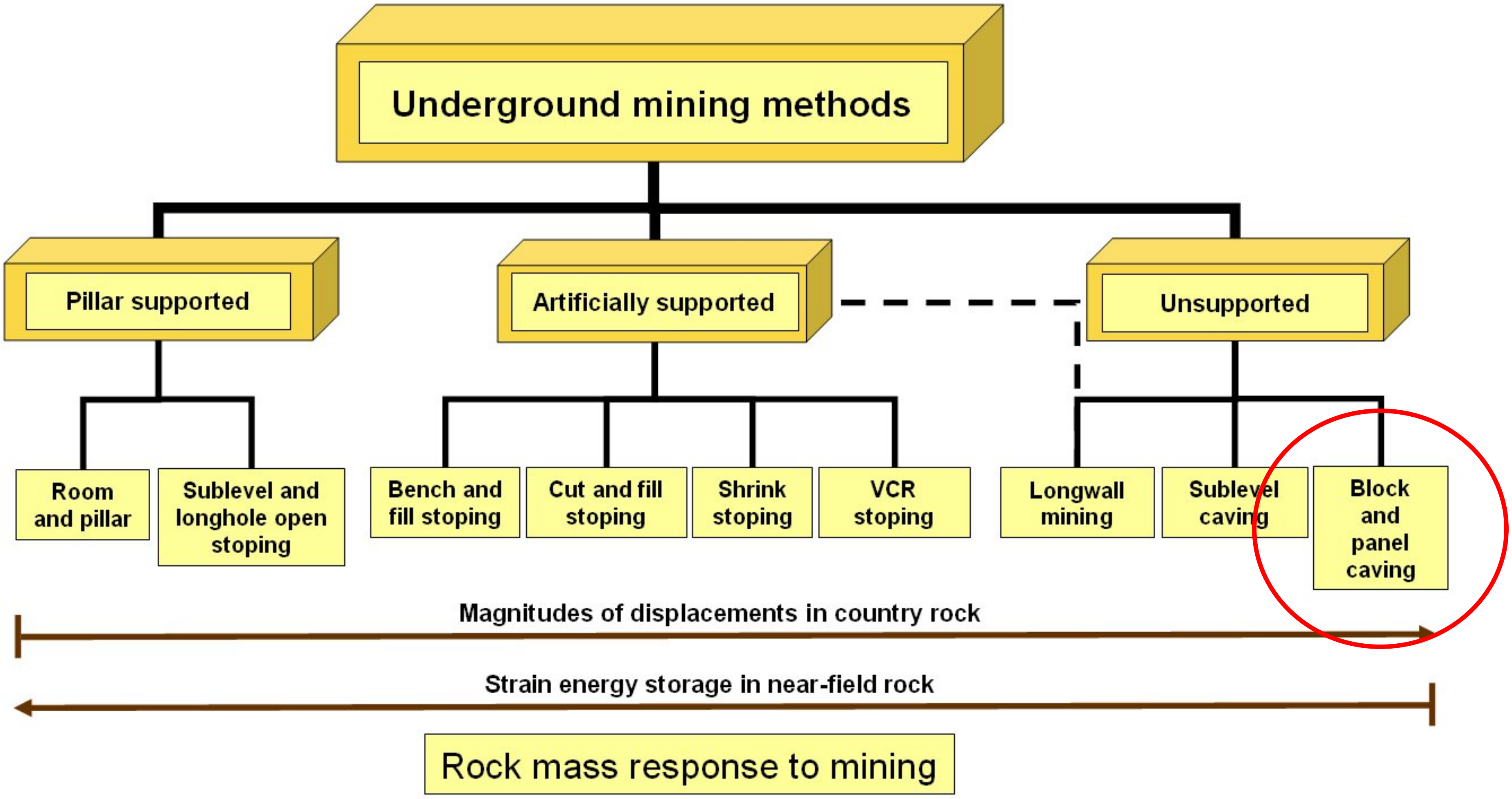
Cave Mining

Caving Mines of the World

Cu-Au Porphyry Cave Mines

Cave Mining Challenges

Cave Mining



After E. T. Brown 2005

WHY CAVING?

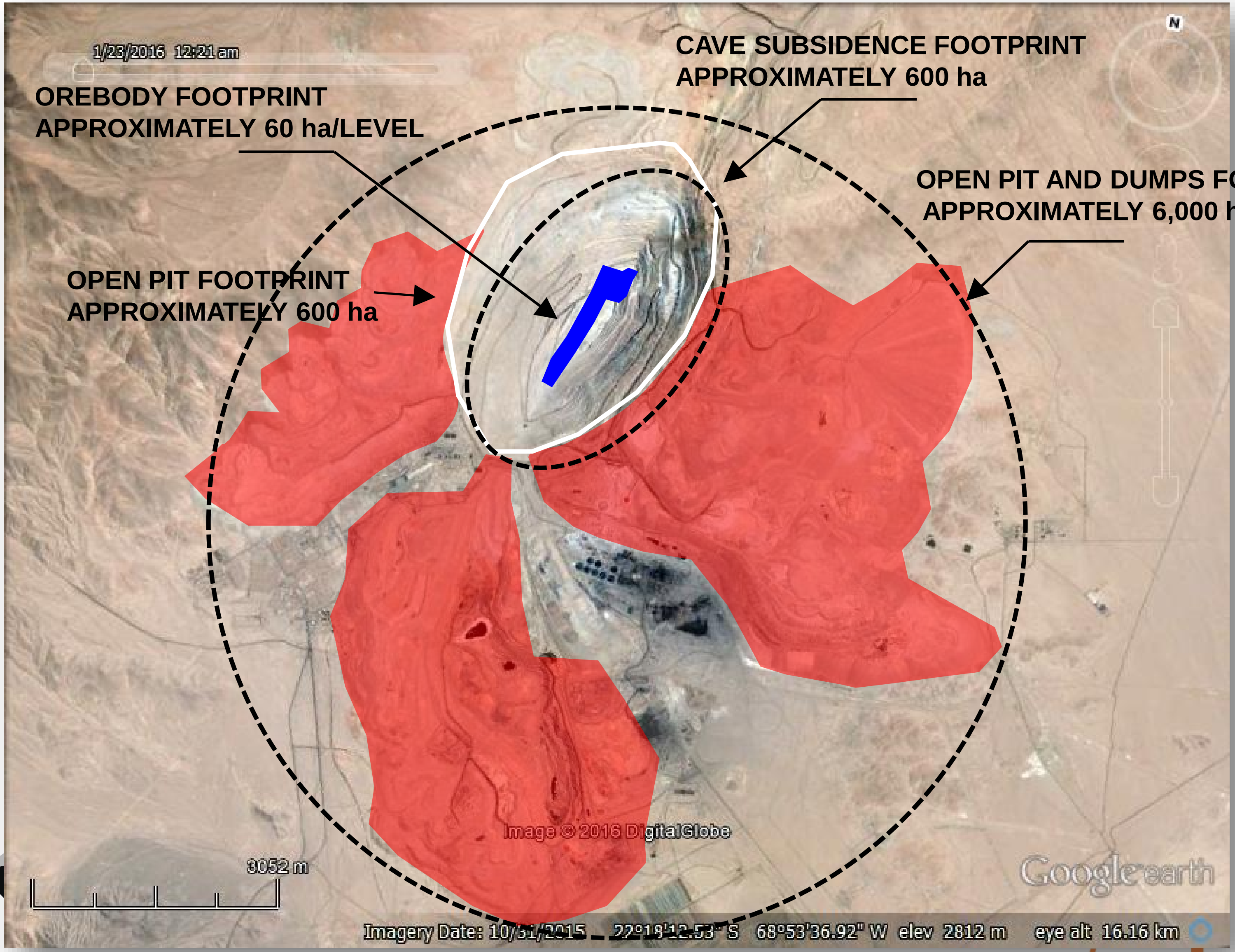
- **High production rates:**
  - **Today's mines 30 - 60 ktpd**
  - **Today's projects > 120-140 ktpd**

- **Lowest mining costs per ton compared to any underground mining method - $4-7/t**

- **Suitable for automation – ore factory concept**

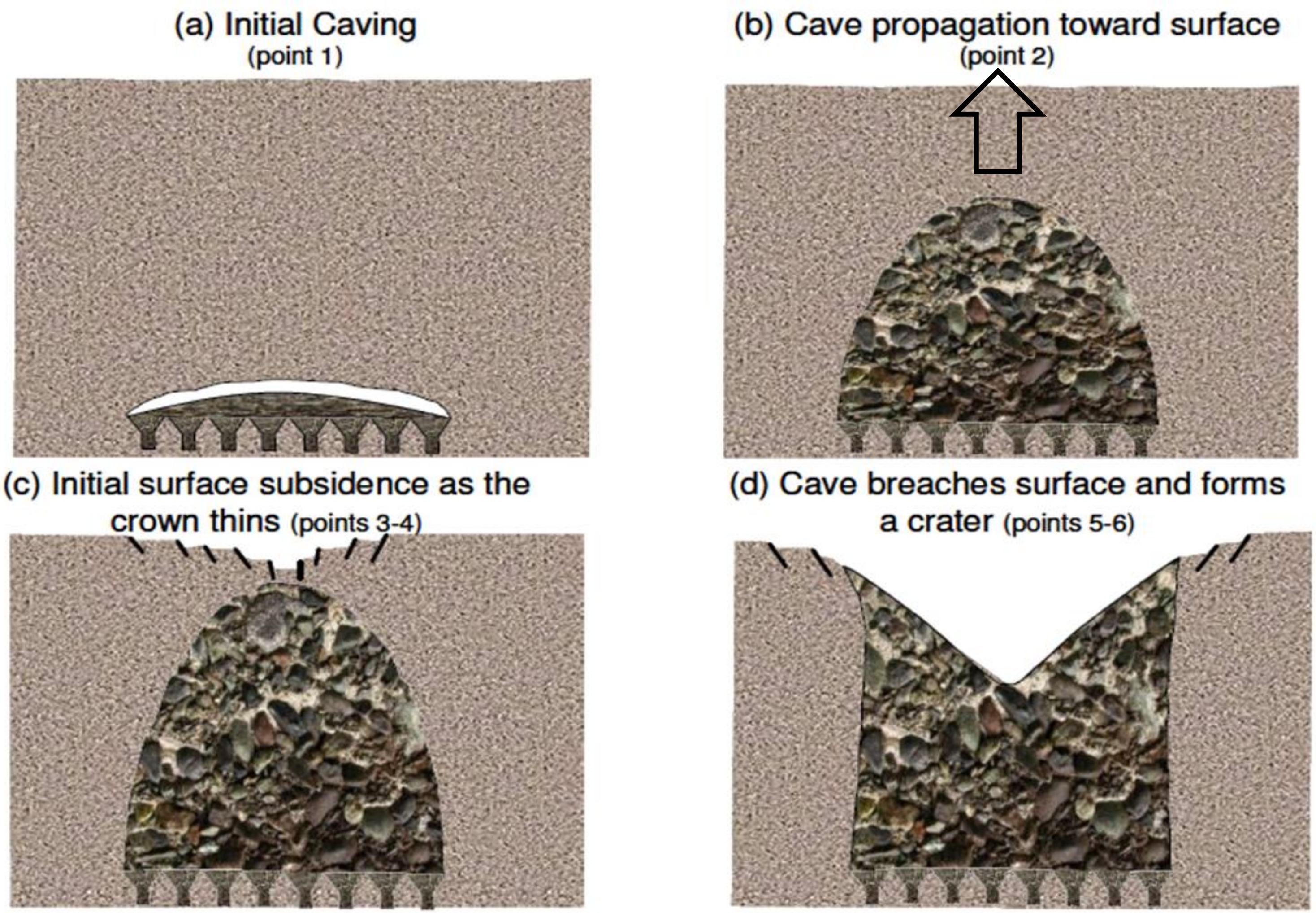
- **Small damage footprint compared to open pit methods**

Environmental Impact

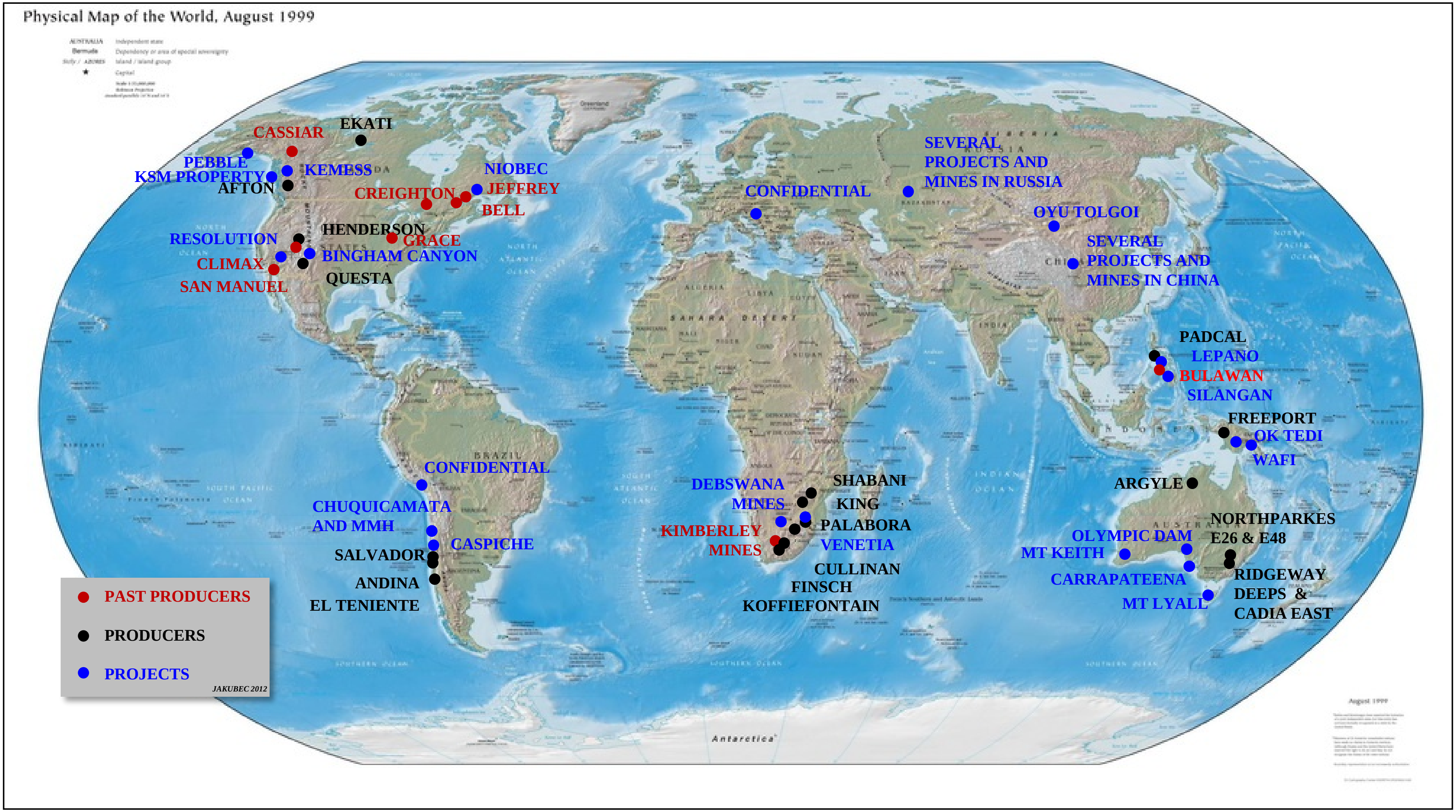


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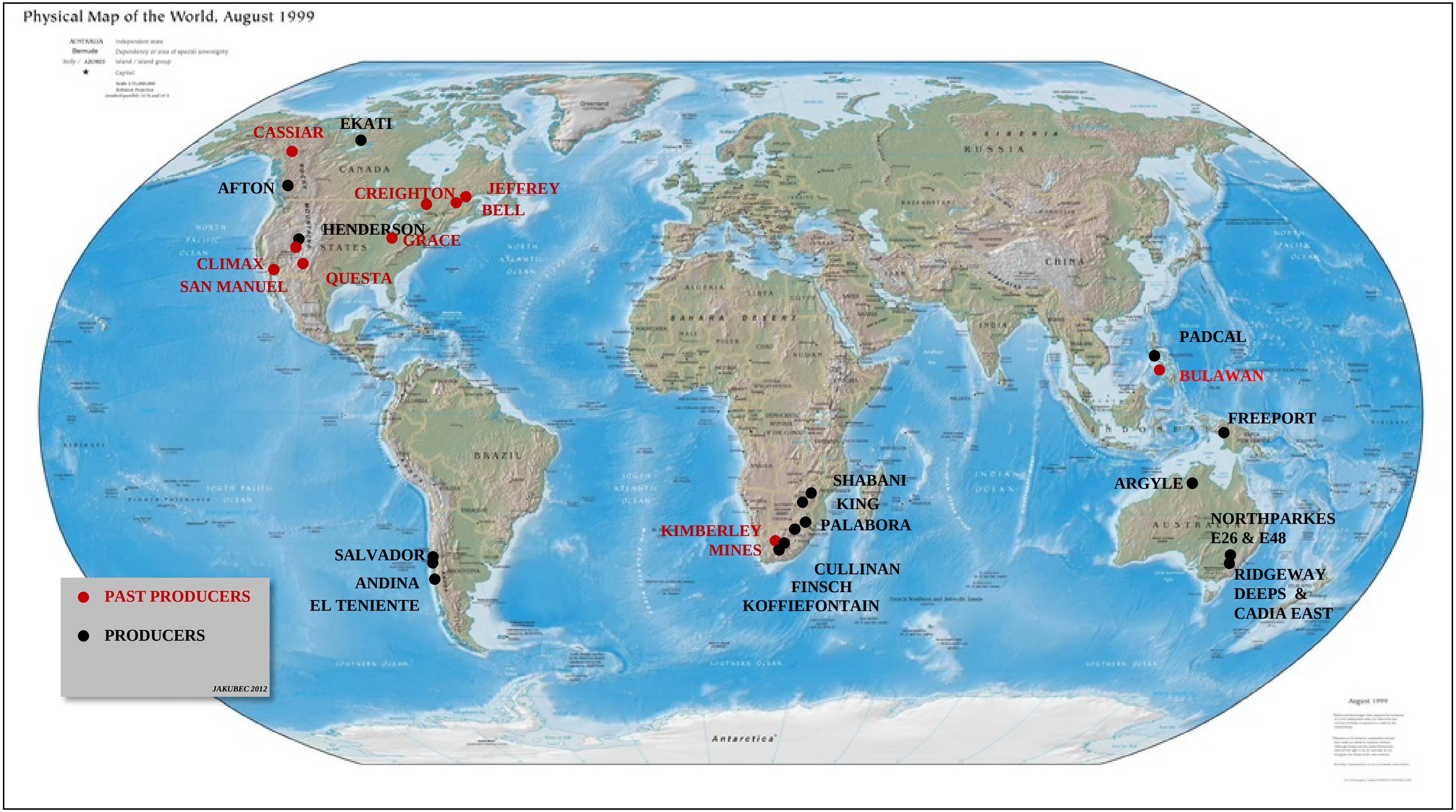
Cave Mining Concept



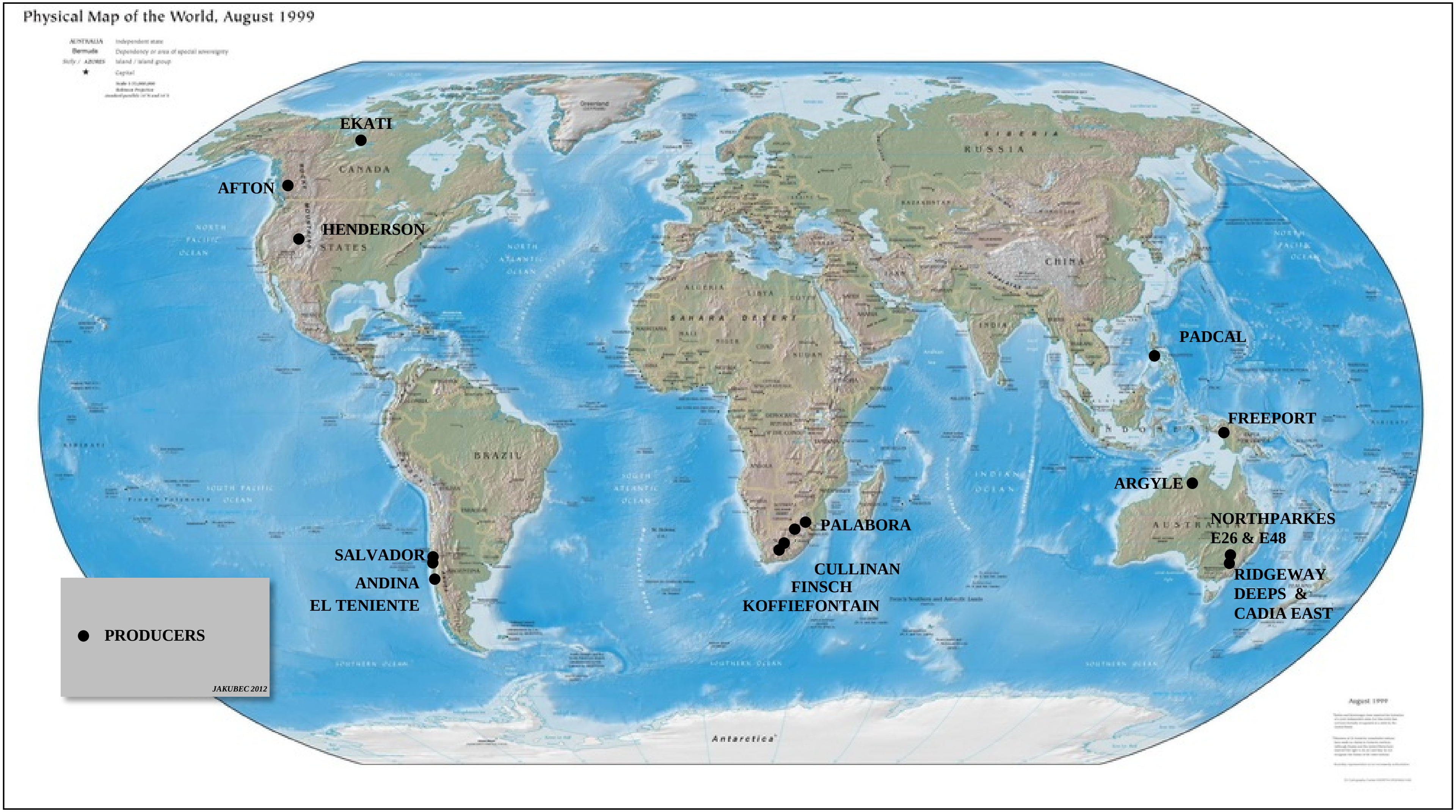
Cave Mines and Projects



Cave Mines – Current and Past Producers



Cave Mines – Current Producers



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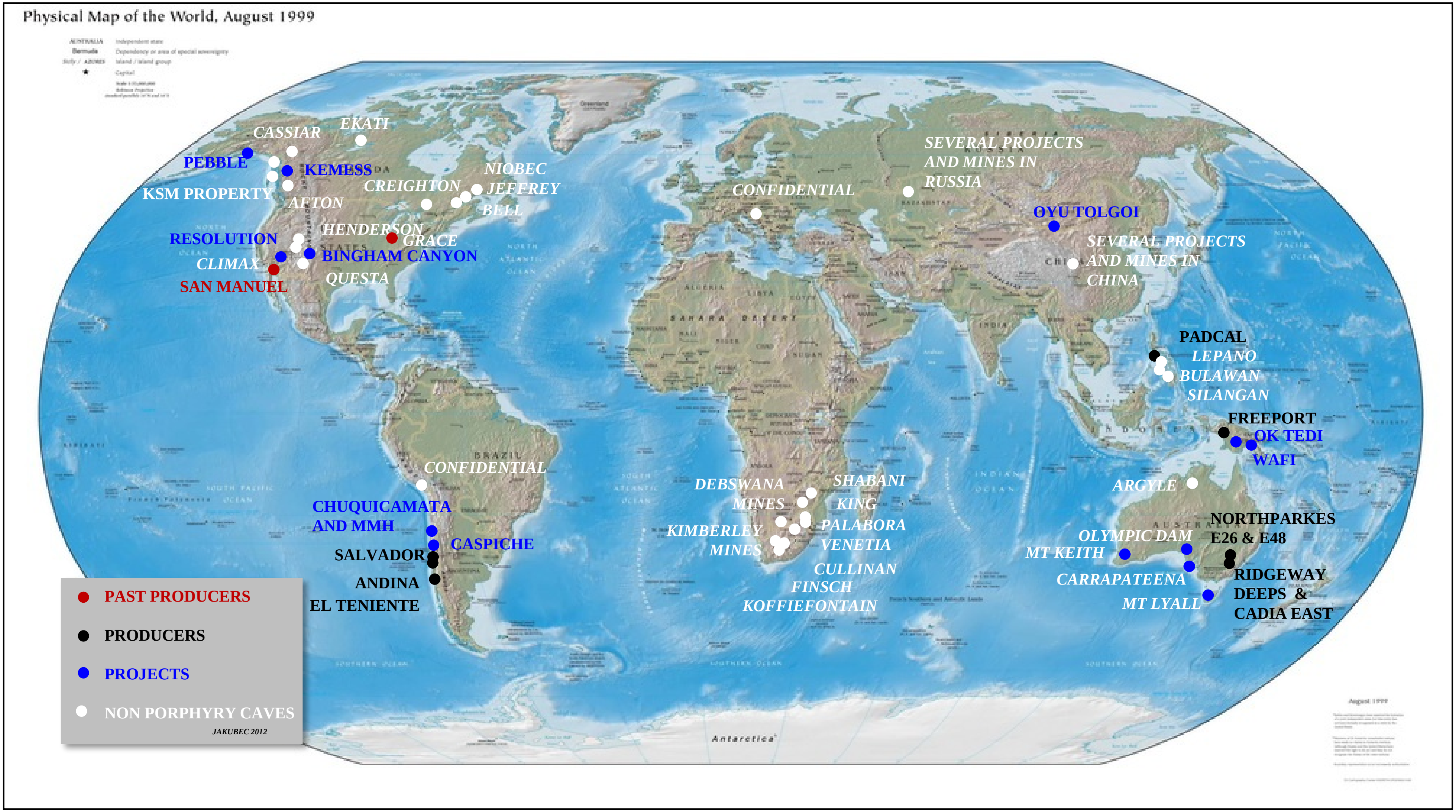
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Cave Mines – Cu Au Porphyry

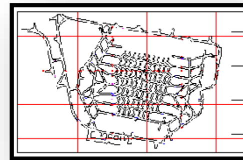
Country	Name	Project	Mine
Chile	Cerro Colorado		
Chile	Chuquicamata	x	
Chile	Collahuasi	x	
Chile	Escondida	x	
Chile	El Abra		
Chile	El Salvador		x
Chile	El Teniente		x
Chile	Caracoles	x	
Chile	MMH	x	
Peru	Toquepala		
Peru	Cerro Verde		
USA	Ajo, Arizona		
USA	Bagdad, Arizona		
USA	Lavender Pit, Bisbee, Arizona		
USA	Morenci, Arizona		
USA	Pebble Mine, Alaska	x	
USA	Safford Mine, Safford, Arizona		
USA	San Manuel, Arizona		x
USA	Sierrita, Arizona		

Country	Name	Project	Mine
USA	Resolution Copper, Superior, Arizona	x	
USA	El Chino, Santa Rita, New Mexico		
USA	Ely, Nevada		
USA	Bingham Canyon Mine, Utah	x	
USA	Ray Mine, Arizona		
Indonesia	Batu Hijau, Sumbawa	x	
Indonesia	Grasberg, West Papua		x
Indonesia	Tujuh Bukit, Java		
Indonesia	Sungai Mak, Gorontalo		
Indonesia	Cabang Kiri, Gorontalo		
Indonesia	Cadia-Ridgeway Mine, New South Wales		x
Indonesia	Northparkes, New South Wales		x
PGN	Ok Tedi	x	
PGN	Panguna/Bougainville Copper		
PGN	Wafi Golpu	x	
Serbia	Chukari Peku	x	
Mongolia	Oyu Tolgoi	x	
Mexico	La Caridad, Sonora		
Philippines	Dizon		

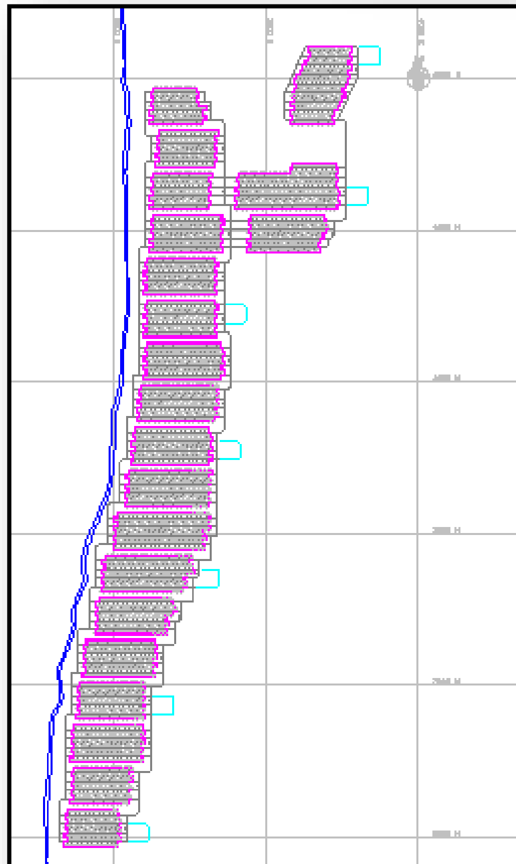
Cave Mines – Cu Au Porphyry

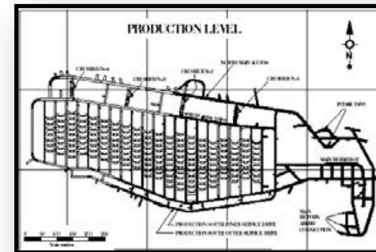


Cave Mines - Footprints

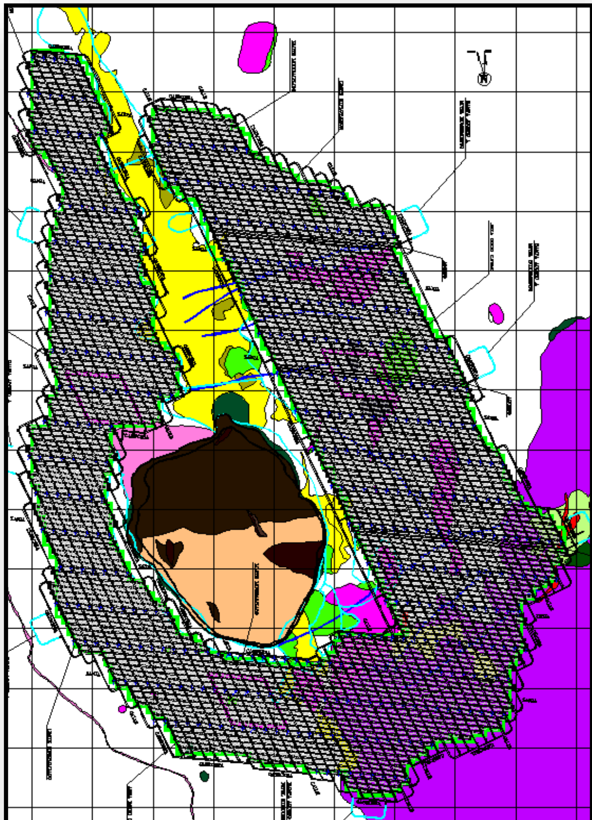


Northparkes E26/1Area: < 5 ha

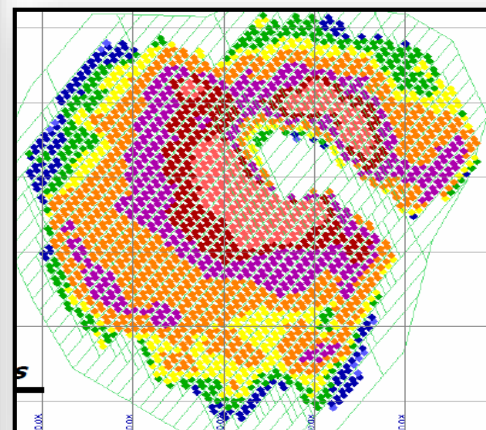




Palabora Area: 12 ha



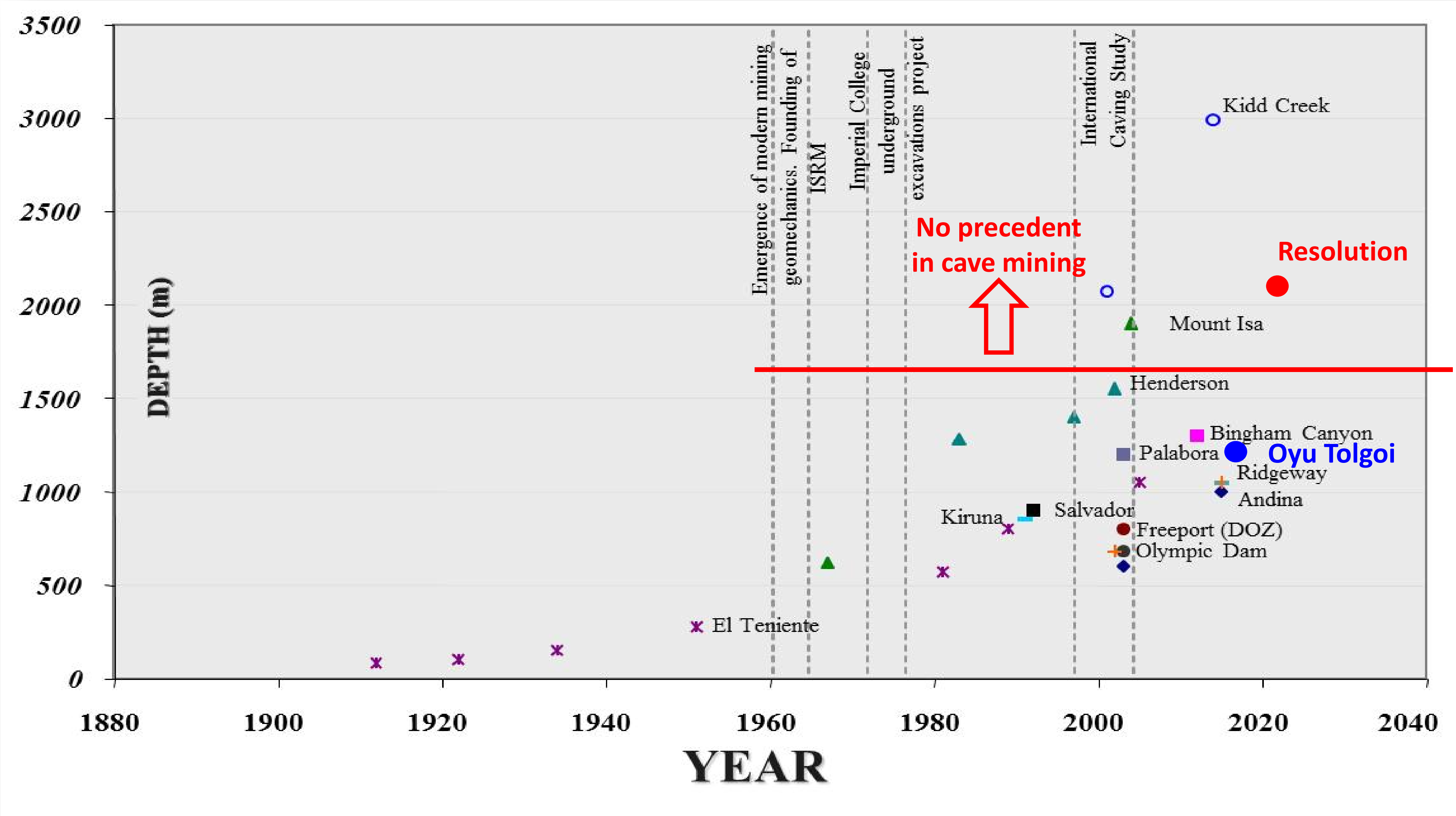
Nuevo Nivel Mina, Teniente
Area: 250 ha



Grasberg Area: 70 ha

Chuquicamata Area: 63 ha per level,
247 ha total

Cave Mines and Projects



After E. T. Brown 2005

COMMENTS ON DESIGN PROCESS

Cave Mines – Design Criteria

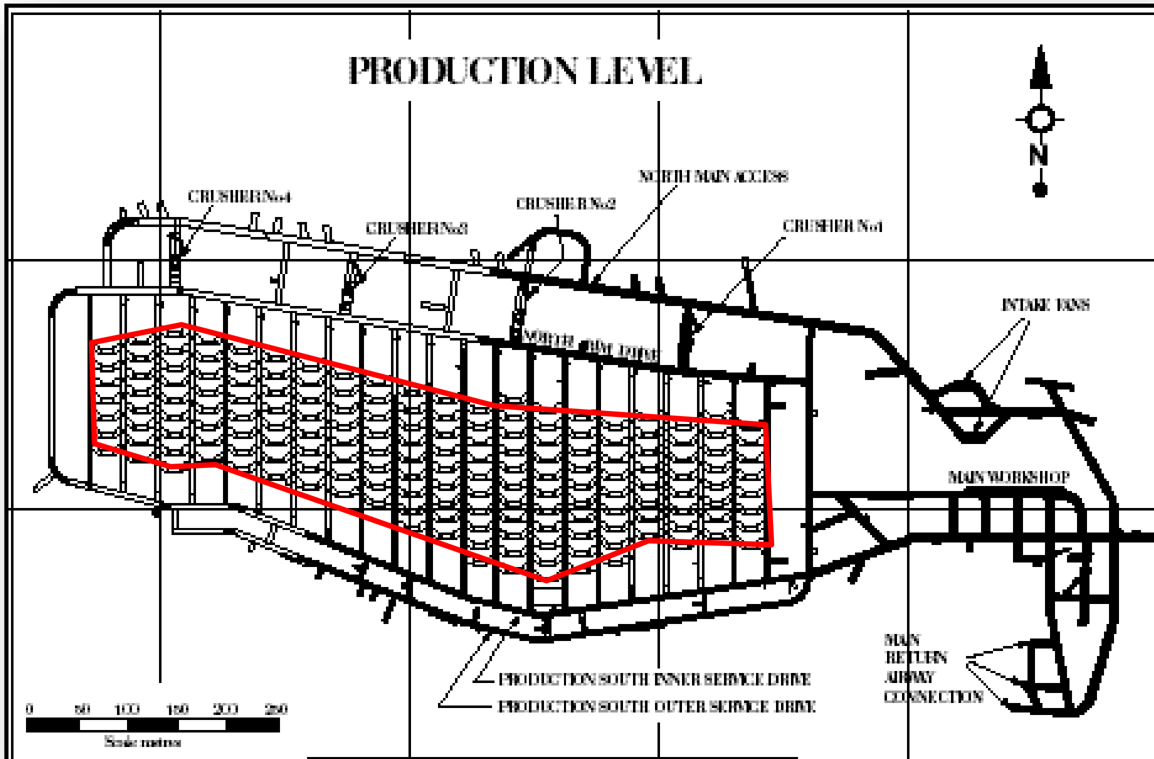
- GEOLOGICAL LOGGING
- GEOTECHNICAL LOGGING
- POINT LOAD TESTING
- DENSITY MEASUREMENT
- DOWN HOLE SURVEY
- CORE ORIENTATION
- JOINT MEASUREMENT
- AQUIFER DEFINITION
- WEATHERING ASSESSMENT
- LABORATORY TESTING
- STRESS ASSESSMENT

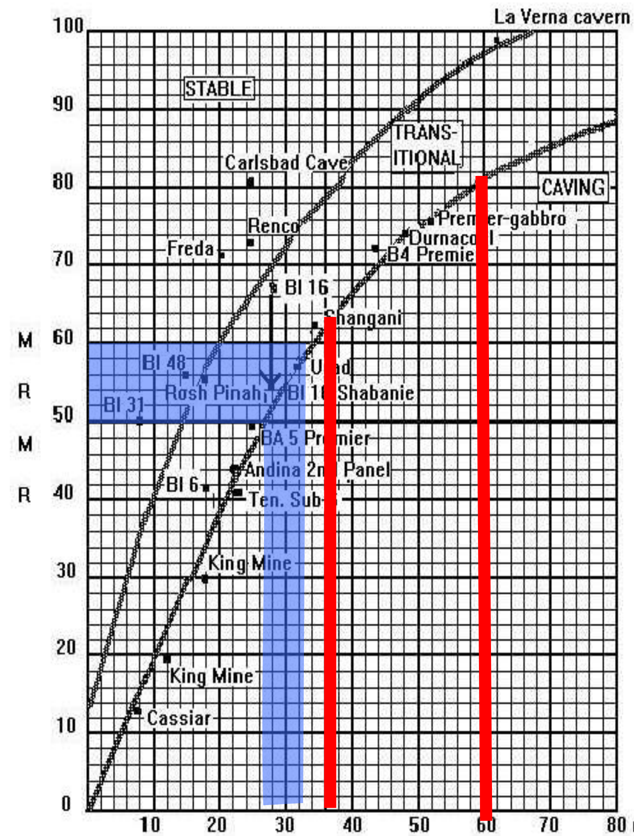
- LITHOLOGICAL UNIT DEFINITION (MATERIAL ZONES)
- ROCK MASS PROPERTIES (MRMR, DENSITIES, DRMS)
- STRUCTURAL PROPERTIES (ROUGHNESS, ORIENTATION, FREQUENCIES)
- HYDROLOGICAL PROPERTIES (AQUIFER DISTRIBUTION)
- MATERIAL PROPERTIES (INTACT ROCK STRENGTH, JOINT STRENGTH, DENSITIES)
- STRESS CHARACTERIZATION (MAGNITUDE AND ORIENTATION)

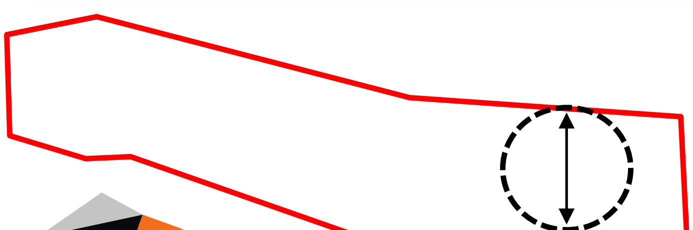
- CAVABILITY ANALYSIS
- STABILITY ANALYSIS
- FRAGMENTATION ANALYSIS
- SUBSIDENCE ANALYSIS
- MUD FLOW RISK ASSESSMENT

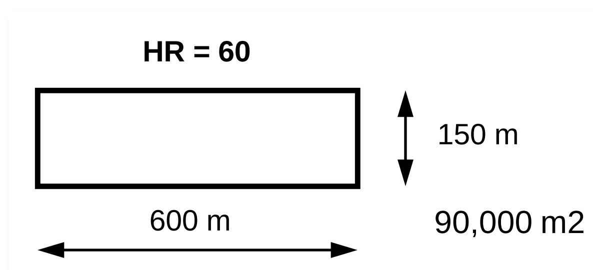
- METHOD SELECTION
- UNDERCUT STRATEGY
- PRODUCTION LAYOUT/SUPPORT
- PRODUCTION RATES/ EQUIPMENT

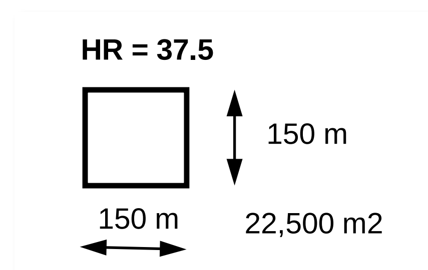
Caveability











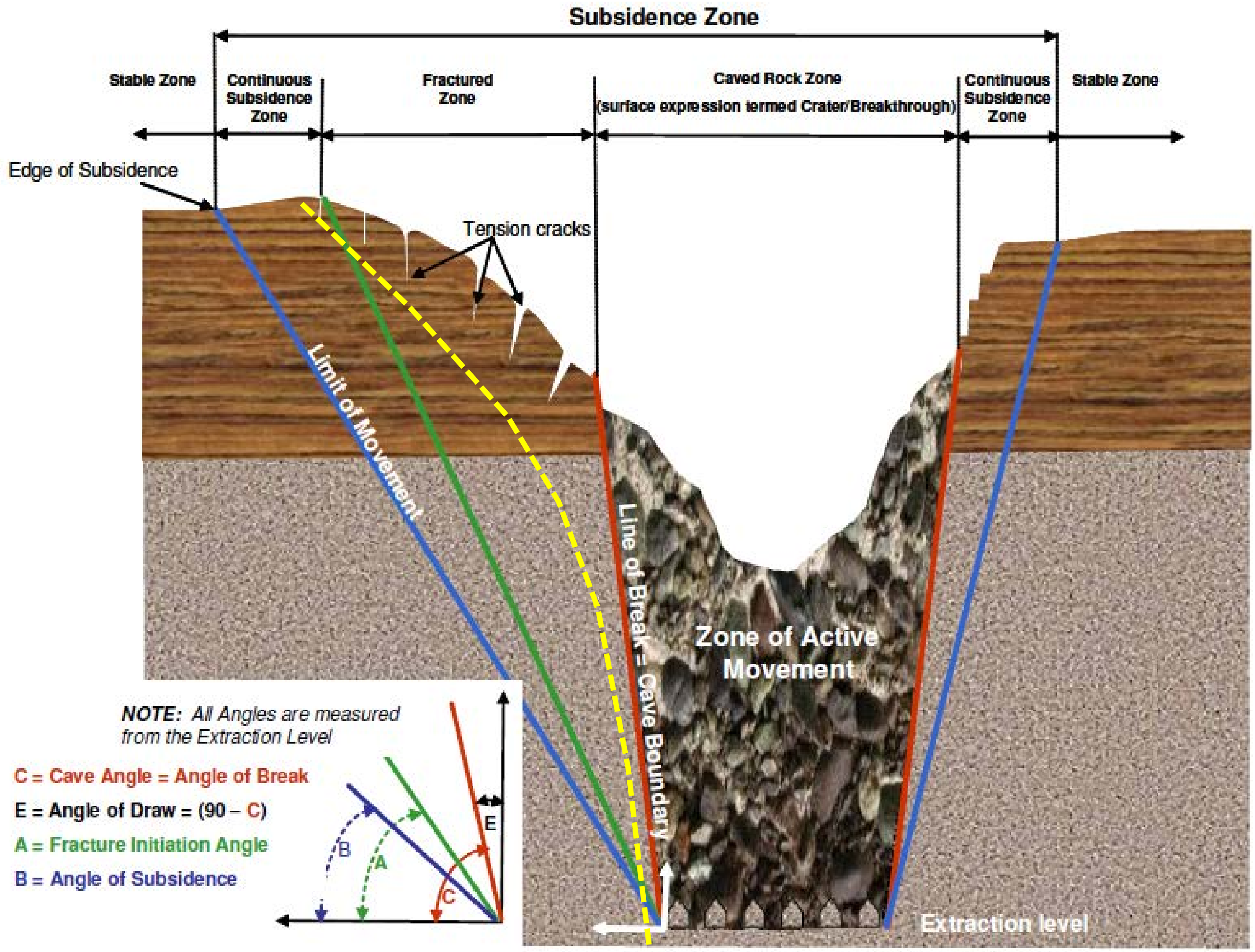
Fragmentation

CAVE MINING REQUIRES THAT ROCK FRAGMENTS ITSELF INTO SUITABLE BLOCK SIZES WITHOUT BLASTING.

FRAGMENTATION MUST BE KNOWN BEFOREHAND AS IT INFLUENCES:

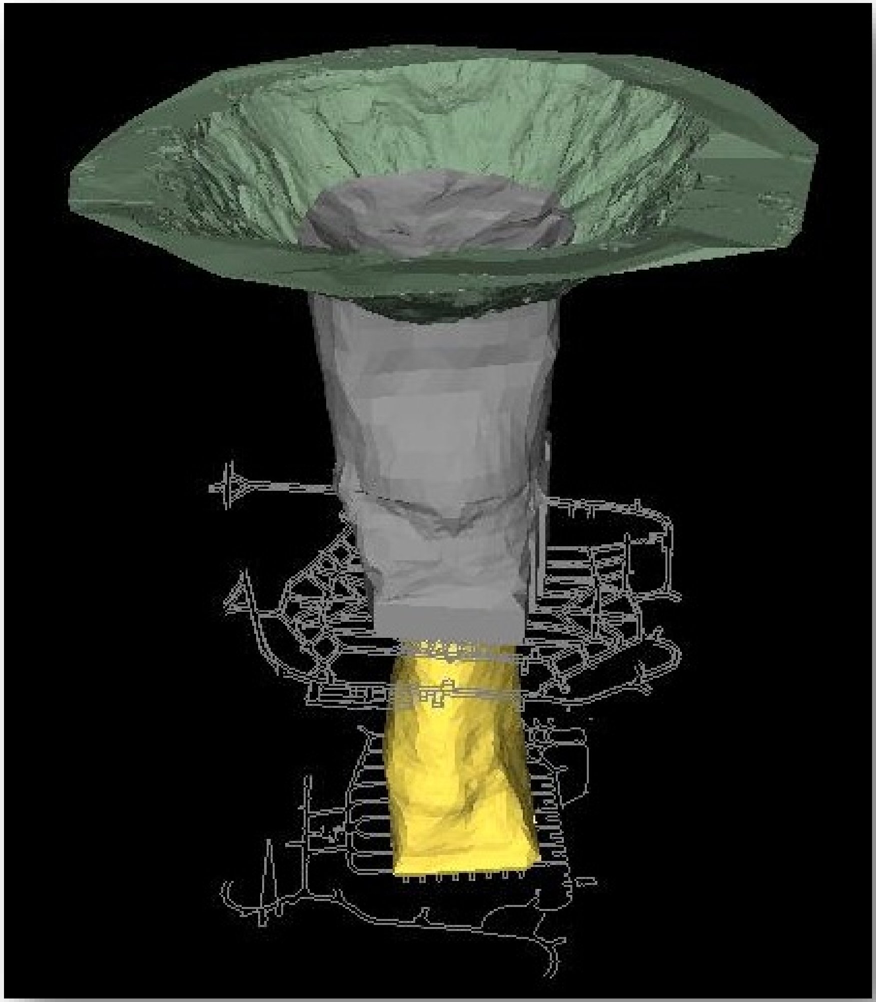
- **DRAWPOINT SPACING**
- **AMOUNT OF SECONDARY BLASTING**
- **HANGUPS AND DELAYS**
- **PRODUCTION RATES AND DRAW CONTROL**
- **DRAWPOINT AND DRAWBELL SIZE**
- **EQUIPMENT SIZE AND TYPE**
- **RAMP UP PERIOD**

Subsidence



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Subsidence



The risk of poor subsidence estimates is typically related to infrastructure location outside the subsidence limits (below). In smaller footprints and strong rock masses the subsidence angles could be negative (overhang) resulting in ore loss and early dilution!



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Active Open Pit Mining in Subsidence Zone



PRE-CONDITIONING, SUPERCAVES AND VERY HIGH LIFTS

Supercave Projects

SUPERCAVES PROJECTS (production rates over 100 ktpd)

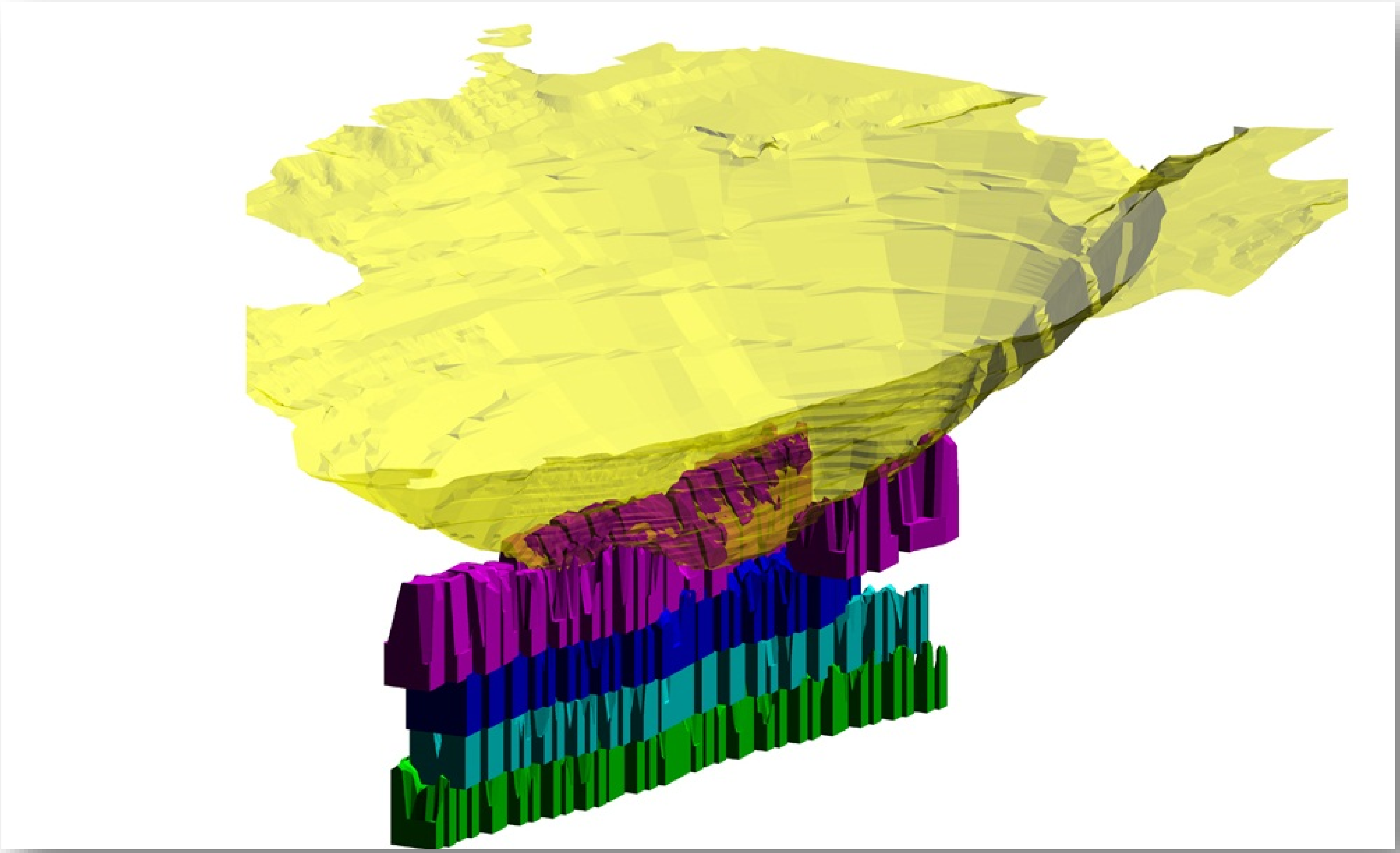
- **EL TENIENTE NEW MINING LEVELS**
- **GRASBERG COMPLEX**
- **CHUQUICAMATA**
- **OYU TOLGOI**
- **RESOLUTION**
- **BINGHAM CANYON**
- **PEBBLE**

The question is how many will materialize!

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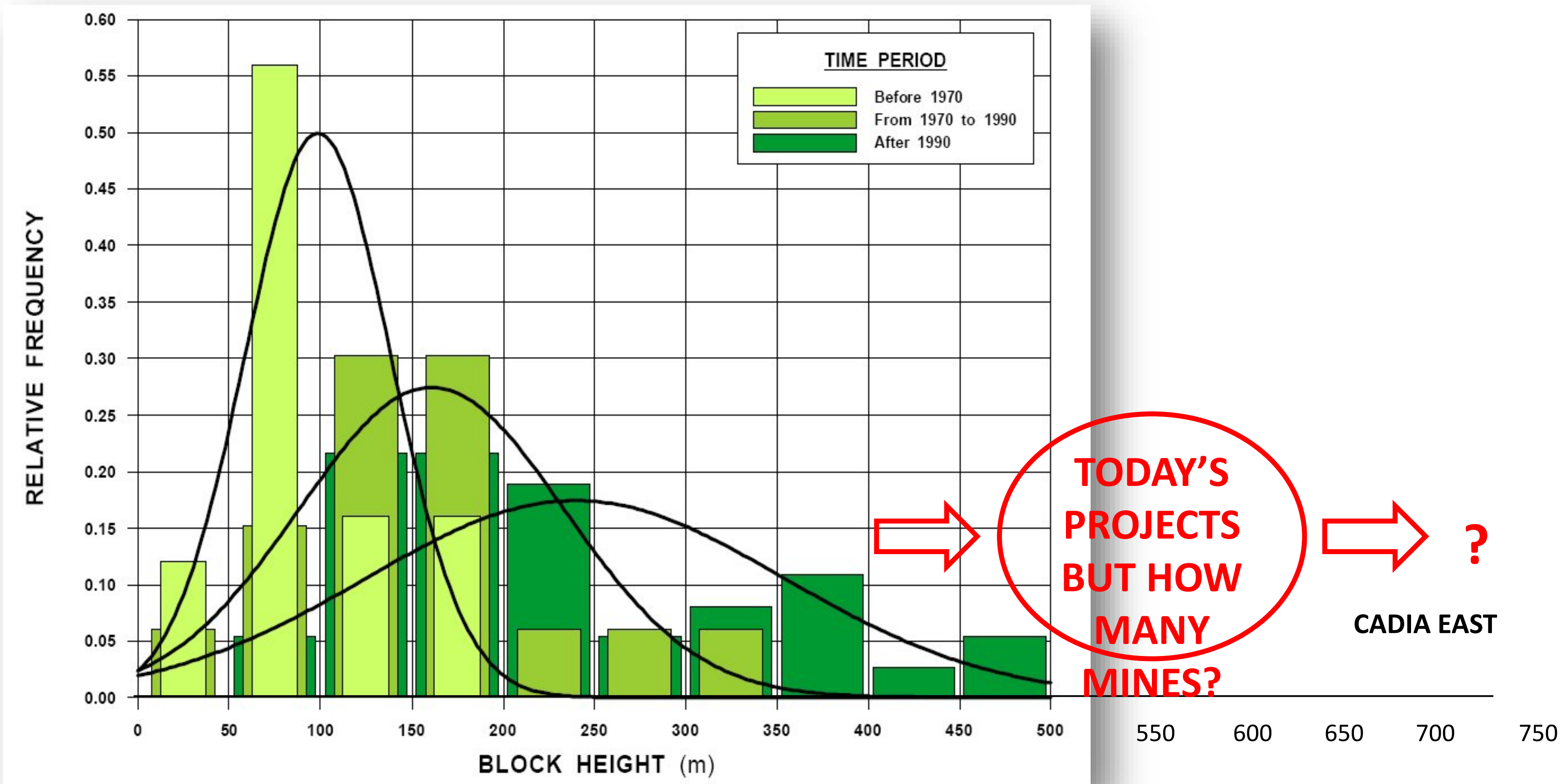
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Supercaves

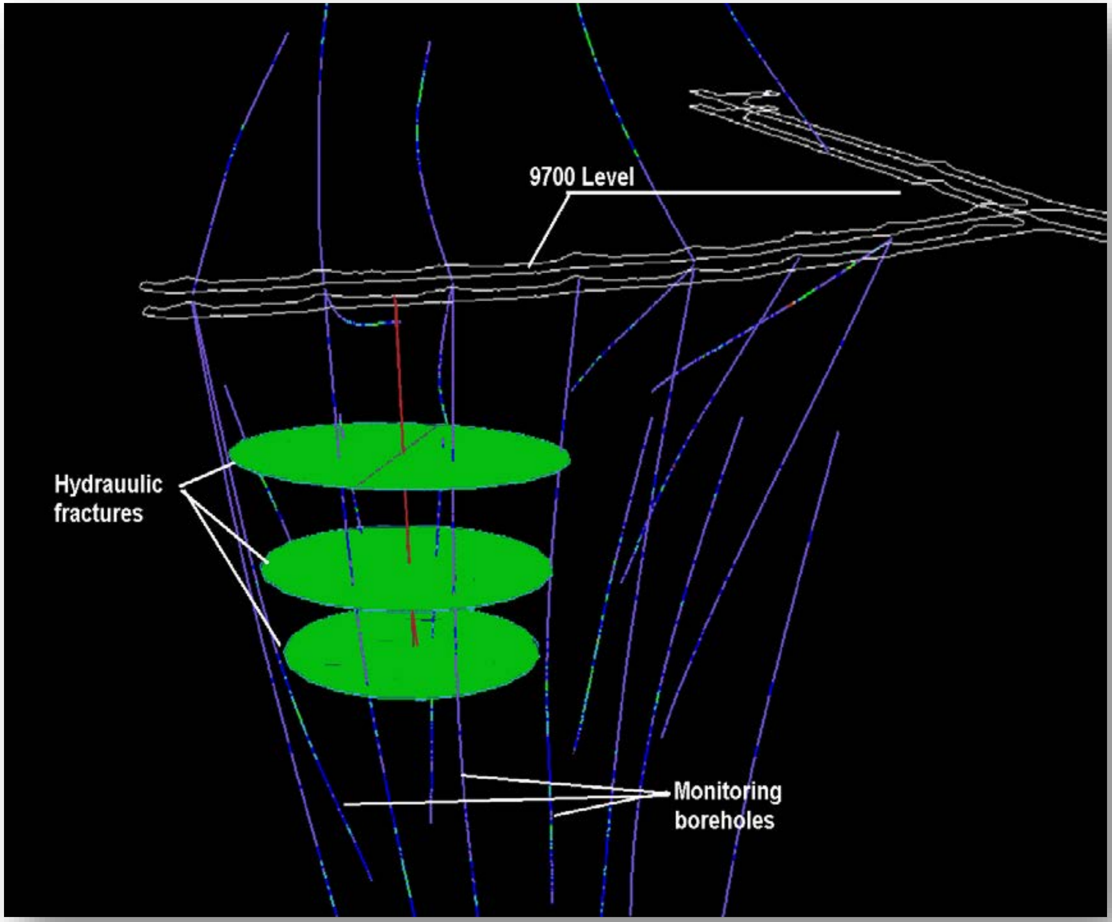


Project reserves 1.656 Mt @ 0.71% Cu – for 90 years!

Supercaves


TIME PERIOD
Before 1970
From 1970 to 1990
After 1990
RELATIVE FREQUENCY
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
BLOCK HEIGHT (m)
TODAY'S PROJECTS BUT HOW MANY MINES?
?
CADIA EAST

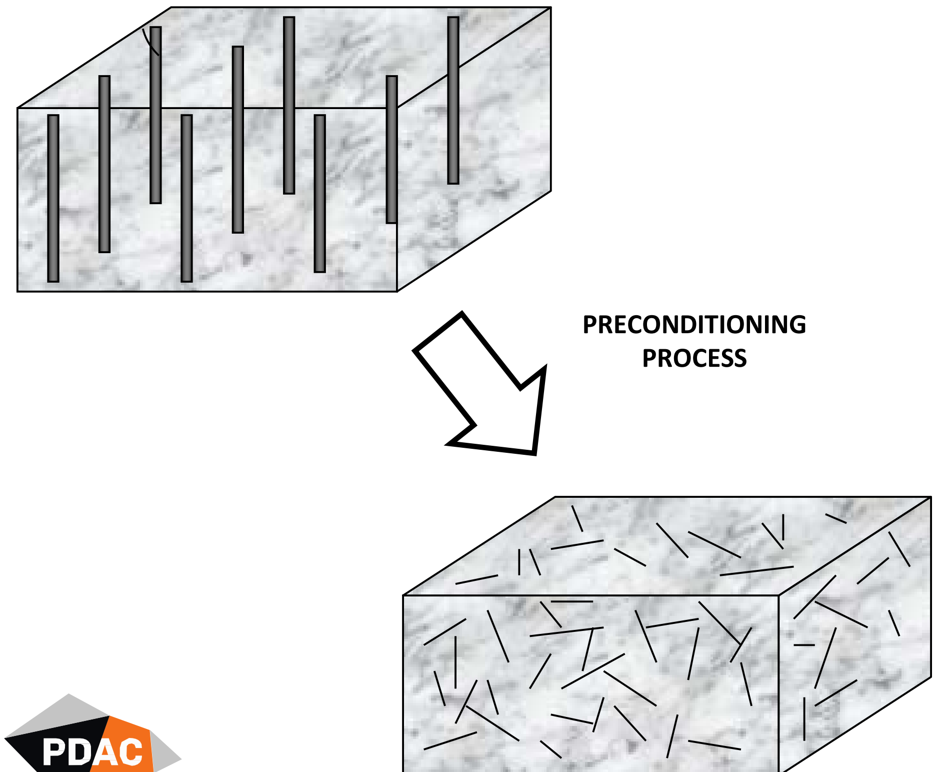
Preconditioning

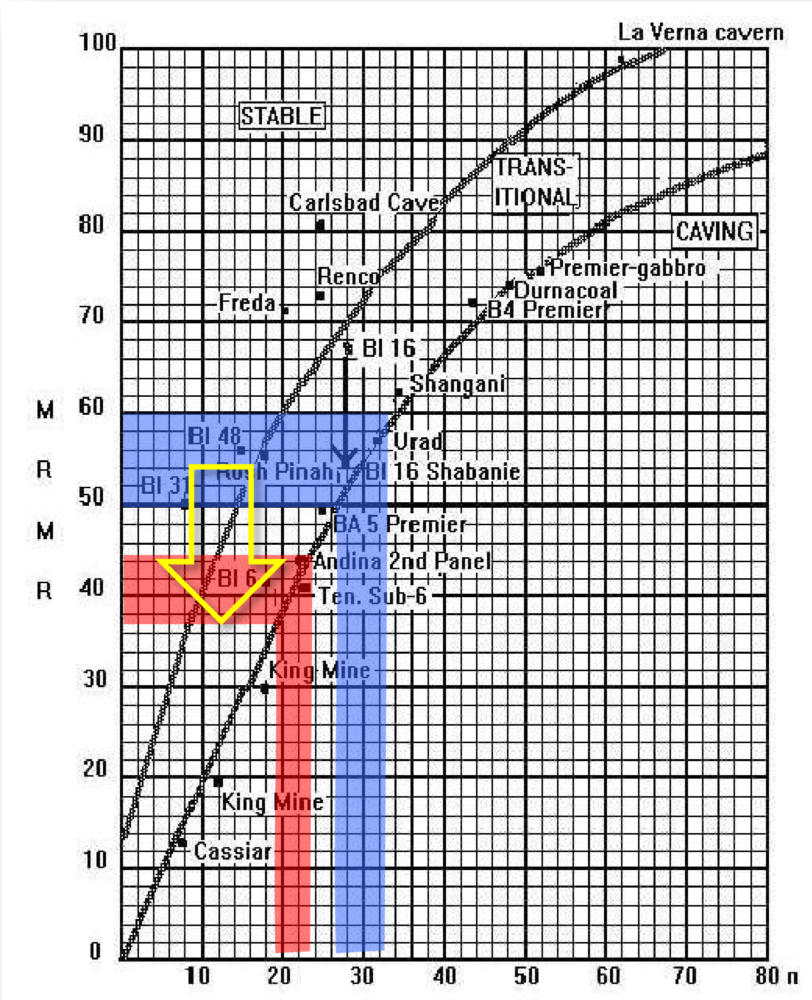


Transform a highly competent rock mass (primary rock) into a rock mass material appropriate for caving methods.

Preconditioning

Transform a highly competent rock mass (primary rock) into a rock mass material appropriate for caving methods.





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WHAT CAN GO WRONG?

Technical Challenges

ACCESS DEVELOPMENT

- STRESS, WATER, GROUND CONDITIONS, STRESS (UNDERGROUND EXPOSURE PRIOR TO COMPLETION OF FS)
- POOR GROUND SUPPORT DESIGN AND/OR INSTALLATION (QA/QC)

CAVE DEVELOPMENT

- UNDERCUTTING STRATEGY
- CAVEABILITY PREDICTIONS
- GROUND SUPPORT AND DEVELOPMENT RATES
- ABUTMENT STRESS DAMAGE
- SEISMICITY

Technical Challenges

RAMP UP

- DRAW RATE PREDICTIONS
- FRAGMENTATION PREDICTIONS
- AIR BLAST AND ROCKBURSTS
- LARGE SCALE WEDGE LOADING

PRODUCTION

- FINES INGRESS, MUDRUSHES AND WATER INFLOW
- BROW WEAR AND STABILITY
- SECONDARY BLAST DAMAGE
- COMPACTION AND STABILITY
- SUBSIDENCE & WEDGE LOADING
- DILUTION

Principal Safety Risks

Cave mining is one of the safest underground mining method. Once the cave is commissioned, personnel is not exposed to unsupported ground, blasting etc. During the development of the cave the main risks are:

- **AIRBLASTS**
- **SEISMIC BURSTS AND COLLAPSES**

During the production the main risk is:

- **MUDRUSH AND FINES INGRESS**

Stability

STABILITY OF THE CAVE MINING LEVELS (UNDERCUT, PRODUCTION AND MATERIAL/VENTILATION) IS AS IMPORTANT AS DRAWPOINT INTERACTION

STABILITY IS IMPACTED PRINCIPALLY BY THE FOLLOWING ACTIVITIES:

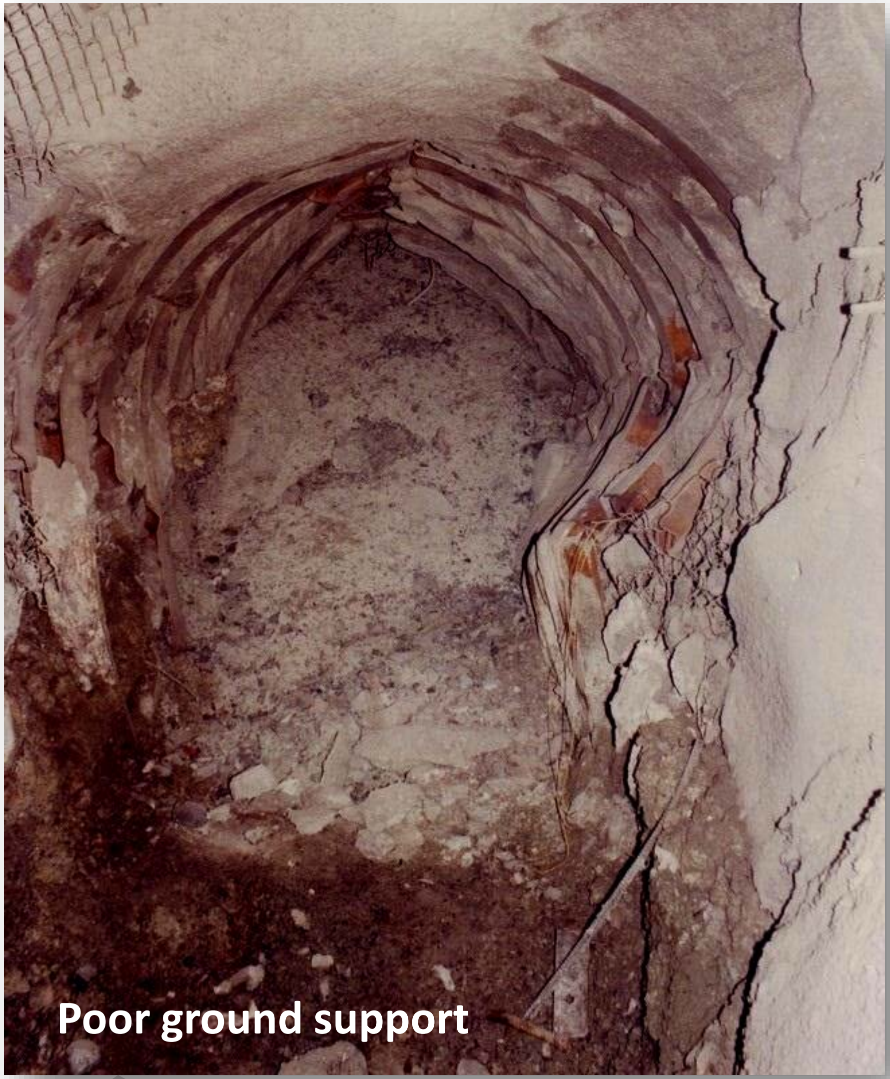
- UNDERCUTTING STRATEGY – ABUTMENT STRESS
- GROUND SUPPORT DESIGN AND QUALITY INSTALLATION
- DRAW STRATEGY

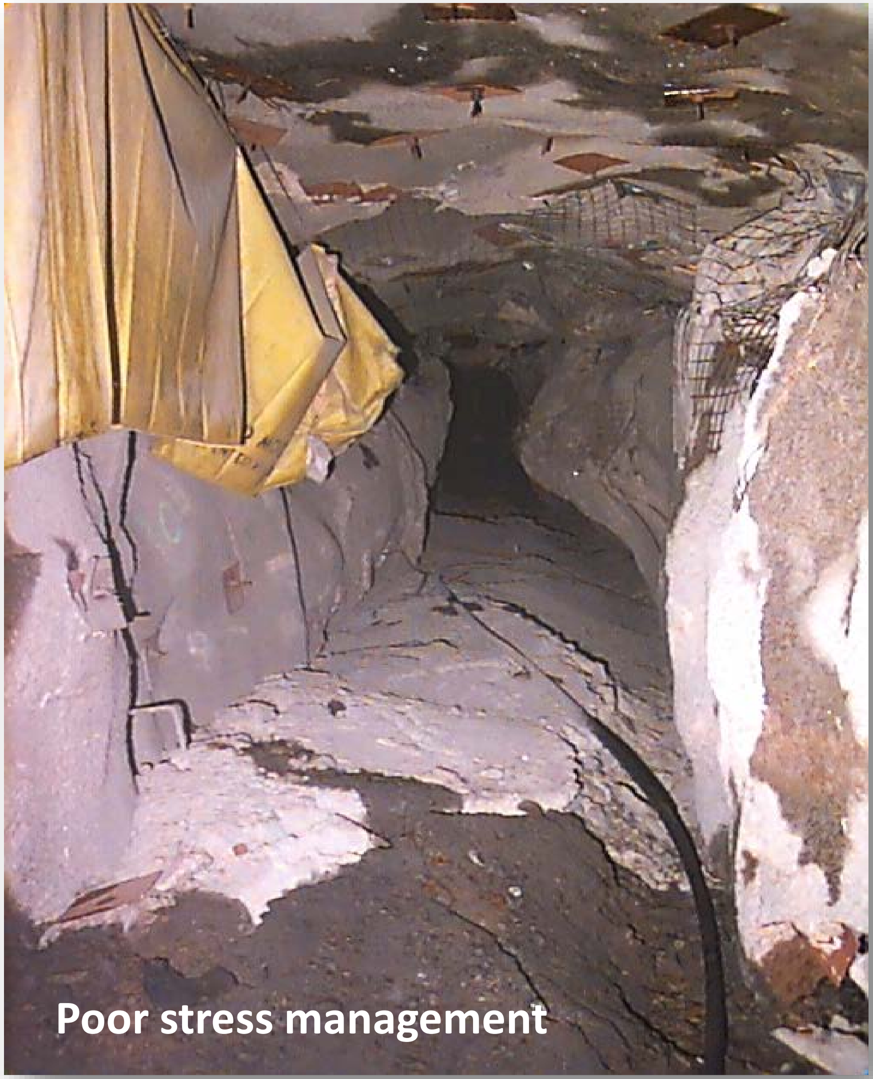
Stability



Typical rockburst damage, UCL drift, Ten sub 6 El Teniente (1991)

Stability





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Mudrush

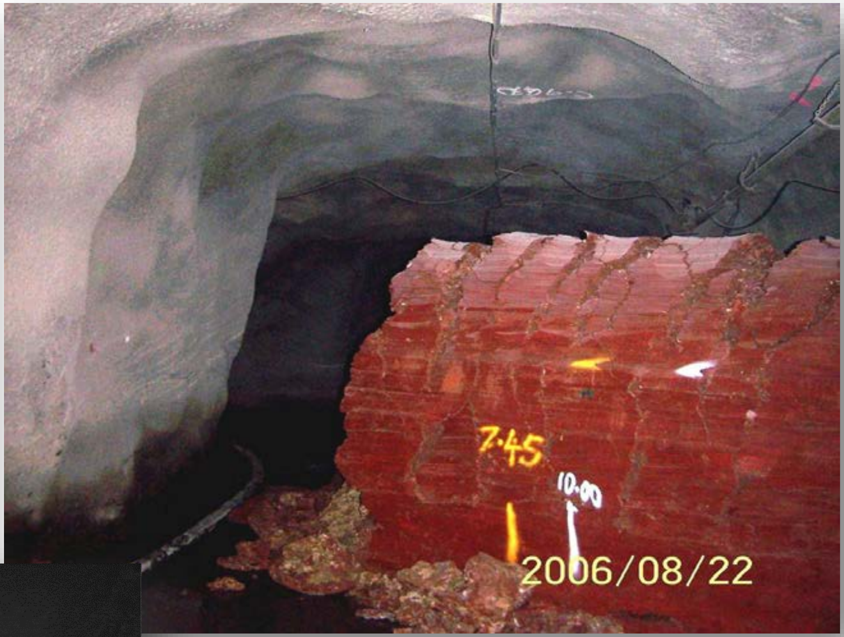
One of the potential hazards that should be evaluated during early stages of the mining study is that of a mudrush.

Several terms have been used in the industry to describe the sudden ingress of wet material into underground workings. The most common are mudrush, mudflow, mudpush, and wet muck.

All of them describe the phenomenon, which can have very different origins but produce the same result: injury, loss of life, damage to property, excess dilution, production delays or closure of a mine.

Mudrush





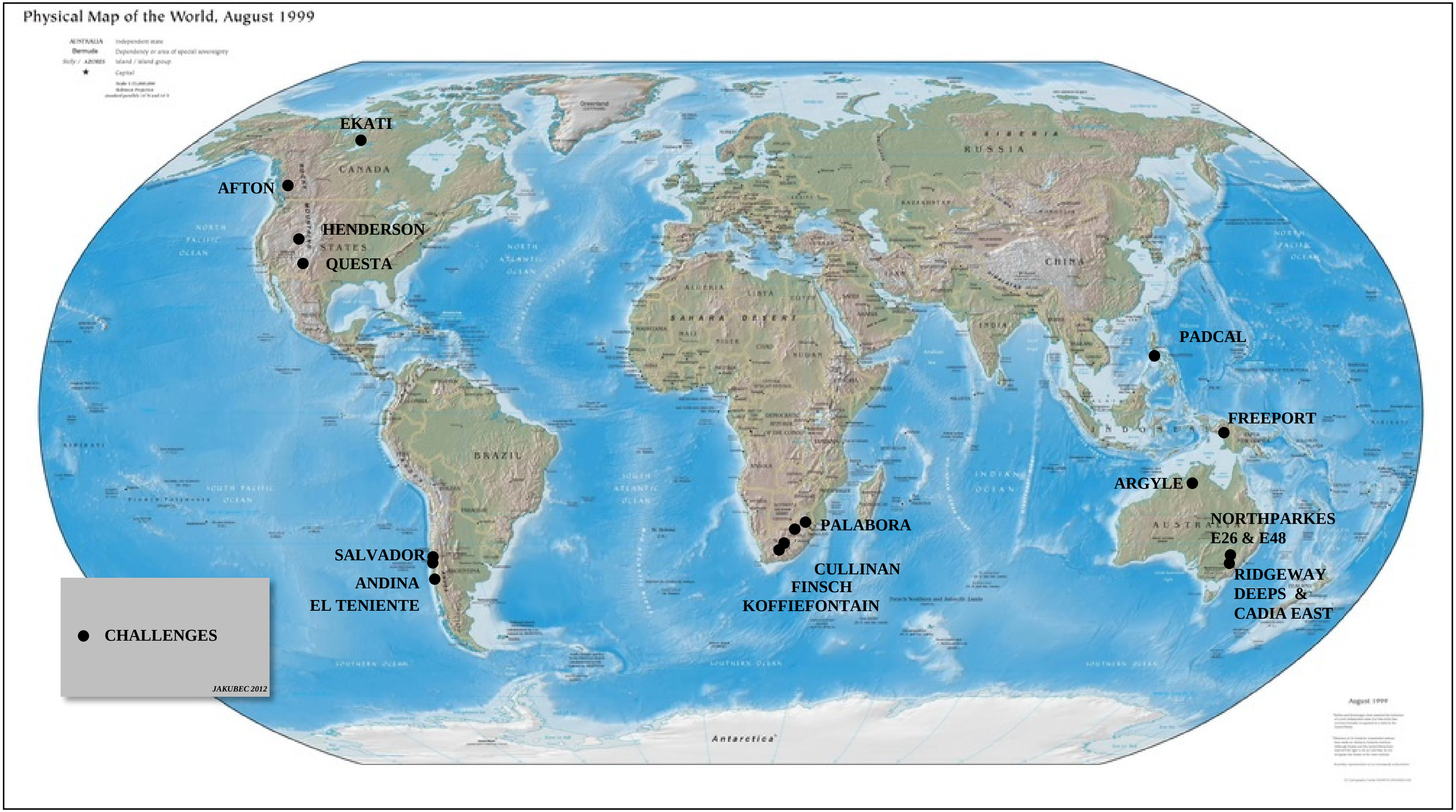


Highly mobile mudrush in Cullinan Mine (left) and stiff clays at E26 Northparkes

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Cave Mines - Challenges



THANK YOU FOR YOUR ATTENTION!



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